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PROCEEDINGS OF THE TOMSK POLYTECHNICAL INSTITUTE
imeni S. M. Kirova

(Selected Articles)

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

LOW-POWER DIRECT CURRENT COLLECTOR-FREE GENERATOR

G. A. Sipaylov, A. B. Tsukublin

(Presented by a scientific Seminar of the departments of Electrical Machines and General Electrical Engineering.)

The reliability of the brush-collector assembly in direct current generators is the main reason that the synchronous generator-rectifier (SG-R) system is used in certain special units, for example, in transportation [1] and other areas of technology as sources of direct current. The majority of the currently employed collector-free direct current generators have a synchronous generator with sinusoidal shape of the e.m.f. as a unit to power the rectifier circuit. This means that the quality of the obtained direct voltage of the direct current collector-free generators is considerably lower than in the normal collector generators. Therefore in order to obtain the minimum pulsations of direct voltage, in a number of units special measures have to be taken. In particular, in certain cases, an increased number of generator phases are used [2], fairly complicated cascade rectification circuits are used [3], a leveling filter is installed [4], etc.

Analysis of the listed methods for reducing pulsations of the rectifier voltage showed that they either result in a decreased use of the power unit (increase in the number of phases) or in complication of the circuit, or increase in the number of rectifier elements. It is natural that these measures are impermissible in systems of limited dimensions and weight where questions of the use of the power unit are primary.

In the manufacture of direct current collector-free generators of low power, in a number of cases installation of a smoothing inductive-capacitance filter is quite impermissible since its overall dimensions signficantly increase the overall dimensions of the entire unit.

One of the methods for producing high-quality voltage in the synchronous generator-rectifier system is the selection of the appropriate shape of the e.m.f. curve that with a load guarantees the minimum pulsations of the rectifying voltage. In this case, the unacceptable condition is also the preservation of a high coefficient of utilization of the synchronous generator.

Both of these conditions are satisfied fairly well if a three-phase synchronous generator with trapezoidal shape of the e.m.f curve and bridge circuit of the rectifier block is used as the power unit.

In order to compensate for voltage dips that appear with a load, a special system of windings on a rotor is suggested which guarantees the trapezoidal shape of the generator voltage in a load.

Device and Operating Principle

The schematic for the low-power direct current collector-free generator with low pulsation level of the output voltage is presented in figure 1. The block of the generator stator 1 does not differ at all from the stator of normal low-power synchronous generators. A

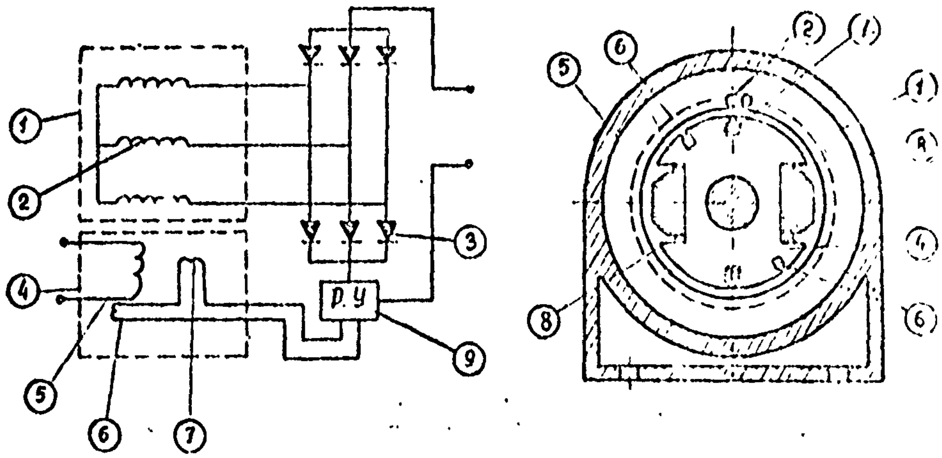

Figure 1.

concentrated three-phase winding with full pitch (2) is placed in the stator slots. The winding phases are connected into a star. If it is not possible to make the concentrated winding, a distributed winding can be used, however,the number of slots per pole and phase should not be more than two, since this will result in a severe complication of the shape of the inductor poles. The stator phases are connected to the bridge rectifier 3 that is the generator outlet.

Generator rotor 4 has a salient-pole design, however, the width of the poles is not selected according to the laws of designing salient-pole machines, but from the condition that the required shape of the e.m.f. curve be obtained.

A distinguishing feature of the rotor is the fact that two windings are placed at each of its poles: the main, 5, which creates the main magnetic flux of the machine, and additional, 6, that is linked

to the generator outlet. The additional winding is selected so that the flux created by it induces in the stator winding an e.m.f. that would compensate for the voltage drops when the generator is loaded on the rectifier. In addition, in order to compensate for the reaction of the armature on the rotor, a compensation winding 7 can be arranged in the transverse axis, although its use in the salient-pole design machines is not mandatory.

In order to exclude the effect of the highest harmonic reaction of the armature on the exciting winding, a damping system is installed on each pole.

In order to balance the rotor and for symmetry of the windings, insulation gaskets 3 are installed on the rotor. The rotor windings are powered by the standard method through rings and a brush apparatus. In this case, the current in the additional and compensation windings is changed according to the law that is determined by the output current through the regulating devices 9, and also by the inductive resistance of scattering of the generator stator winding.

The need for an additional winding to compensate for the voltage dips during loading, can be explained if we examine the commutation process for switching the rectifiers.

The reasons for the appearance of pulsations in the rectified voltage of the synchronous generator-rectifier system with e.m.f. of trapezoidal shape (fig. 2,a) during a load are the transitional electromagnetic processes of switching the rectifiers. When phase A is disconnected and phase B is connected, the anode inductance (scattering inductance of the stator winding) pulls the transitional process of increase (phase B) and decrease (phase A) of the current. Inductive e.m.f. appear in the phases, $L_\phi \frac{di}{dt}$, where L_ϕ--phase inductance, i-momentary value of phase current. These e.m.f. reduce the voltage of the phase that is working, by creating a drop in the rectified voltage (fig. 2,b). The depth of the drops (pulsation) is determined by the quantity of the commutation current, as well as by the amount of anode inductance.

Consequently, at the moment of switching, it is necessary to have that e.m.f. to compensate for the drops in phase voltage.

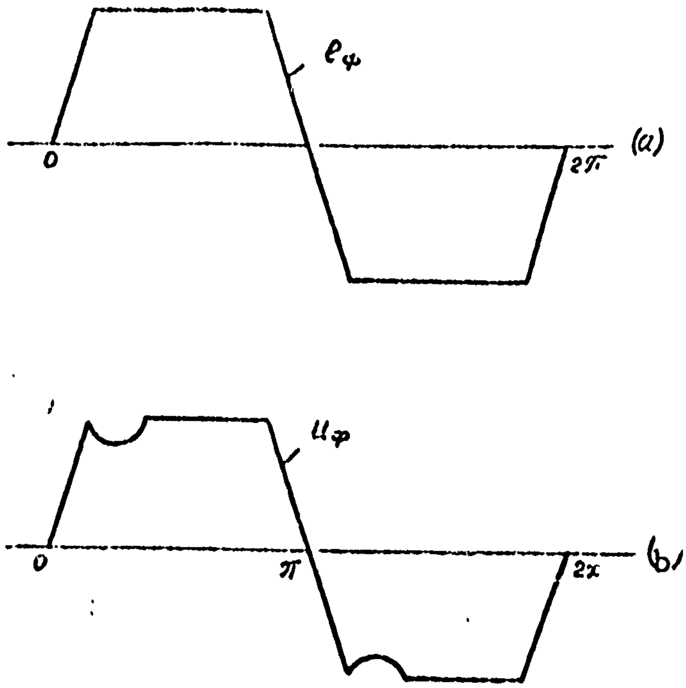

Figure 2.

We will examine how the e.m.f. of the synchronous generator must change if the goal is to obtain ideally smoothed voltage from the three-phase bridge rectifier loaded with an inductive-active load ($L_н = \infty$). In examining this question, we will start from the fact that the reaction of the generator armature does not influence the shape of the generator e.m.f.

It is known from the theory for the operation of multiple-phase bridge rectifiers that the rectified voltage, with ideally smoothed rectifier current can be written in the frequency interval $\frac{\pi}{m}$ by two equations:

1) in the period of current commutation from phase A to phase B

$$U_d = \frac{e_A + e_B}{2} - e_C - \frac{3}{2} I_d r'; \qquad (1)$$

2) in the extra-commutation interval of time during operation of phases B and C

$$U_d = e_B - e_C - 2I_d r' \qquad (2)$$

where I_d--average value of rectified current;

r--total active resistance of generator phase and direct resistance of rectified element.

If it is assumed that in the extra-commutation interval the condition is fulfilled with $\omega t = \gamma - \frac{\pi}{m}$

$$-(e_C - I_d r') = e_B - I_d r' = U = \text{const}, \qquad (3)$$

then the appearance of pulsations of rectified voltage is only possible because of the commutation process. Therefore, in order to obtain ideally smoothed rectified voltage, it is necessary to guarantee at the moment of commutation with $\omega t = 0 \div \gamma$.

$$\frac{e_A + e_B}{2} - e_C - \frac{3}{2} I_d r' = 2U = \text{const}. \qquad (4)$$

Taking into consideration that the generator produces a symmetrical system of e.m.f., i.e., $e_A(t) = e_B\left(t + \frac{2\pi}{m}\right) = e_C\left(t - \frac{2\pi}{m}\right)$

and limited to an examination only of two-three rectifier regime for the operation of the rectififer $\gamma < \frac{\pi}{m}$, one can establish that e_C in expression (4) with regard for (3) is determined

$$e_C = -(U + I_d r') \qquad (5)$$

with $\omega t = 0 \div \gamma$. Consequently, with regard for this, with

$$\frac{e_A + e_B}{2} - \frac{I_d r'}{2} = U = \text{const}. \qquad (6)$$

Assuming from the condition for simplicity that the e.m.f. of the disconnected phase in the period of commutation is changed according to the rectilinear law $e_A = -\frac{U}{\beta}(\omega t - \beta)$, we will find the law for change in the e.m.f. of phase B

$$e_B = \frac{U}{\beta}(\omega t + \beta) + I_d r' \qquad (7)$$

Thus, in order to obtain the minimum pulsations of the rectified voltage of the bridge three-phase rectifier, the synchronous generator must guarantee an e.m.f. whose shape is described by the following

equations;

$$\omega t = -\beta \div 0, \quad e(\omega t) = \frac{U}{\beta}(\omega t + \beta);$$

$$\omega t = 0 \div \gamma, \quad e(\omega t) = \frac{U}{\beta}(\omega t + \beta) + I_d r';$$

$$\omega t = \gamma \div \frac{2\pi}{m}, \quad e(\omega t) = U + I_d r';$$

$$\omega t = \frac{2\pi}{m} \div \frac{2\pi}{m} + \beta, \quad e(\omega t) = -\frac{U}{\beta}\left(\omega t - \frac{2\pi}{m} - \beta\right).$$

The shape of the e.m.f. for this case is given in fig. 3,a. With regard for the reaction of the synchronous generator armature that influences not only the quantity, but also the shape of the phase e.m.f., the calculated e.m.f. curve is distorted and acquires the appearance shown in fig. 3,b. In order to create this e.m.f., it is necessary to have an additional coil on the inductor pole. The size of the additional coil according to the width of the pole is determined by the size of the commutation angle. It can be computed from the approximate formula

$$\gamma = \arccos\left(1 - \frac{I_d x_s}{\frac{4\pi}{m\beta} U \sin\frac{\pi}{m}}\right),$$

where x_s--inductive resistance of generator scattering.

Thus, even with an inductive load, a fairly high-quality direct voltage can be obtained with the use of only a three-phase bridge rectifier.

A similar generator can be used in systems that need direct currrent, in which it is permissible according to the operating conditions to have a brush-collector apparatus and filtering elements.

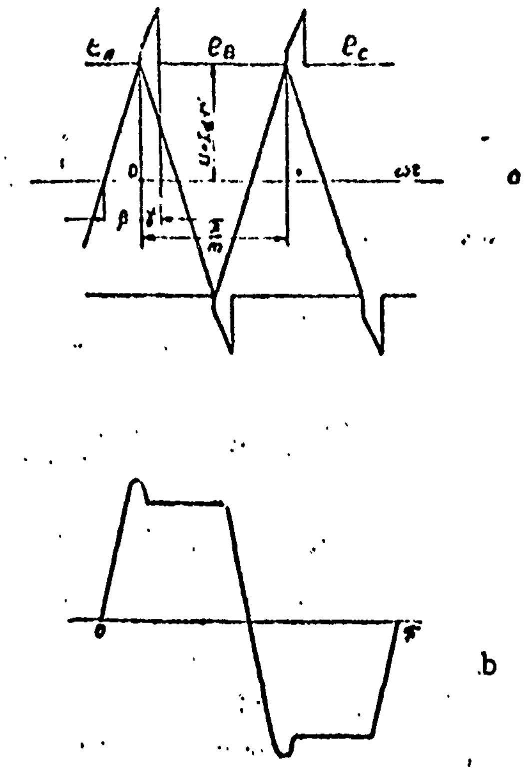

Figure 3.

References

1. А. Ф. Крогерис, Я. К. Шинка. Бесконтактный генератор постоянного тока. Народное хозяйство Советской Латвии, № 5, 1959

2. Г. А. Ковальков. Выпрямительный генератор. Филиал ВИНИТИ АН СССР, № Э 59-11/4, 1959.

3. Г. Г. Федосеев. Выпрямители и стабилизаторы. Госиздат Искусство, 1960.

4. И. А. Левин. Сглаживающие индуктивно-емкостные фильтры выпрямителей. Диссертация, ЛЭТИС, Ленинград, 1962.

SELECTION OF A RECTIFICATION CIRCUIT IN DIRECT CURRENT COLLECTOR-FREE GENERATORS

G. A. Sipaylov, A. B. Tsukublin

(Presented by a scientific Seminar of the departments of Electrical Machines and General Electrical Engineering.)

The question of selecting a rectification circuit appears each time in designing collector-free direct current generators of the synchronous generator-rectifier type. This question becomes especially urgent in designing exciters that are the first cascade of the direct and alternating current collector-free EMU (amplidynes) [1,2]. However, as yet there are no published recommendations on this question.

This article analyzes the selection of the rectification circuit for a low-power direct current collector-free generator of the synchronous generator-rectifier type. The characteristic feature of these units is that they must guarantee the maximum use of the generator in the entire range of load change. In this case it is necessary to take into consideration the simplicity and reliability of the unit, as well as the minimum weight and overall dimensions. From this viewpoint, of all the diversity of rectification circuits, one can only isolate the bridge rectification circuits and the one-half-period when the generator is connected by a star. As for the other rectification circuits (circuits with compensation reactor, cascade circuits, etc.), they are not examined because of their cumbersome design.

An important advantage of the two-half-period rectification circuits over the one-half-period is that during powering from a transformer, they yield a greater utilization coefficient and lower pulsation coefficient for the same load. During powering from a synchronous generator, the operating pattern of the rectifiers changes. This is associated with the presence of an armature reaction in the synchronous generator. It is therefore necessary to make the selection of the rectification circuit with regard for the armature reaction of the synchronous generator, as well as the size of the load.

The following assumptions were made in the analysis:

1. The rectifiers are assumed to be ideal, i.e., direct resistance of the rectifier is not considered, but the inverse, equal to infinity. It needs to be noted that this assumption is not completely arbitrary, if one considers that the low-power machines have a relatively high value of active resistance of the armature winding.

2. The generator produces sinusoidal voltage even under load, i.e., the higher harmonic reactions of the armature that are induced

by the nonsinusoidal nature of the armature current are completely obliterated by the damper rotor loops.

As is known [1,2], the operation of the low-power synchronous generator on a rectification block is characterized by a high $\cos\varphi$ whose values lie in the limits of $\cos\varphi = 1-0.96$. Therefore an accurate degree of precision can be considered the fact that the rectifier [illegible] is active for the generator.

The vector diagram for this case is illustrated in figure 1. According to a certain diagram, the phase voltage with direct excitation current is expressed

$$U_1 = \sqrt{\frac{E_0^2 - 2I_1^2 x_{ad} x_{aq}}{2} + E_0 \sqrt{\frac{E_0^2}{4} - I_1^2 x_{aq}(x_{ad} - x_{aq})}} - I_1 r \quad (1)$$

By expressing the rectification voltages and the current through the known [3] contact coefficients $\frac{U_1}{U_d} = k_{1u}$ and $\frac{I_1}{I_d} = k_{1i}$, and by substituting them in (1), we obtain an equation for the external characteristics of the generator working on the rectifier:

$$U_d = \frac{1}{k_{1u}} \sqrt{\frac{E_0^2 - 2I_d^2 x_{ad} x_{aq} k_{1i}^2}{2} + E_0 \sqrt{\frac{E_0^2}{4} - I_d^2 x_{aq}(x_{ad} - x_{aq}) k_{1i}^2}} - I_d r \cdot k_{1i} \quad (2)$$

Considering that the generator resistances remain constant with a change in the rectification circuit, we find that the incline of the characteristics mainly depends on the coefficients k_{1u} and k_{1i}.

Figure 2 shows the external characteristics of the generator for the one-half-period and two-half-period rectification circuit that were obtained according to equation (2) for a three-phase generator. As is apparent from the curves, at some point (we will call it the critical), intersection of the characteristics occurs, i.e., up to this point the generator produces more power when operating on the bridge rectification circuit. However, with a load that exceeds the critical value, as a consequence of the armature reaction of the generator, the bridge rectification circuit produces values for the generator power that are considerably lower than the one-half-period.

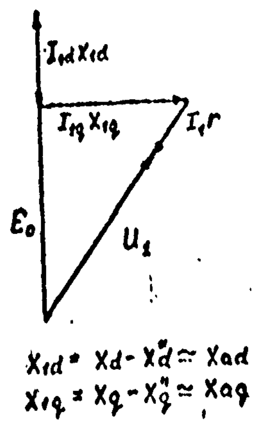

Figure 1. Vector Diagram of Generator

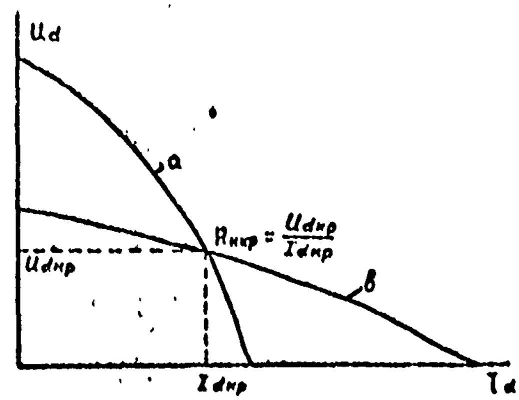

Figure 2. External Characteristics of the Generator
a--with bridge rectification circuit
b--with one-half-period rectification circuit

The value of the load at the critical point and its link to the machine parameters can be obtained by joint solution of equations (2) for the one-half-period and bridge rectification circuits. By designating k_{1u}'' and k_{1i}'' the values for the coefficients for the bridge circuit, and $k_{1u'}$ and $k_{1i'}$ for the one-half-period, we obtain

$$\left[\frac{\left(R_{нкр}\frac{k_{1i}'}{k_{1u}'}+r\right)^2+x_{aq}^2}{\left(R_{нкр}\frac{k_{1i}''}{k_{1u}''}+r\right)^2+x_{aq}^2}\right]^{\frac{1}{2}} = \frac{k_{1u}'}{k_{1u}''}\cdot\frac{\left(R_{нкр}\frac{k_{1i}'}{k_{1u}'}+r\right)^2+x_{ad}x_{aq}}{\left(R_{нкр}\frac{k_{1i}''}{k_{1u}''}+r\right)^2+x_{ad}x_{aq}} \quad (3)$$

The solution of this equation in relation to $R_{нкр}$ produces a link between the critical load and the generator parameters. For machines with uniform air gap, equation (3) is simplified by means of $x_{ad}=x_{aq}$ and $x_{1d}=x_{1q}=x_d$, and acquires the appearance:

$$\frac{k_{1u}'}{k_{1u}''} = \left[\frac{\left(R_{нкр}\frac{k_{1i}''}{k_{1u}''}+r\right)^2+x_d^2}{\left(R_{нкр}\frac{k_{1i}'}{k_{1u}'}+r\right)^2+x_d^2}\right]^{\frac{1}{2}}. \quad (4)$$

The solution to this equation results in simple ratios between the load resistance and the generator parameters

$$R_{\text{нкр}} = \frac{-r\Delta k_p + \sqrt{r^2\Delta k^2_p - z_r\Delta k_{1i}\Delta k_{1U}}}{\Delta k_{1U}} \quad (5)$$

where

$$\Delta k_p = k_{1U}' k_{1i}' - k_{1U}'' \cdot k_{1i}'',$$
$$\Delta k_{1U} = (k_{1U}')^2 - (k_{1U}'')^2,$$
$$\Delta_{k1i} = (k_{1i}')^2 - (k_{1i}'')^2,$$
$$z_r^2 = x_d^2 + r^2.$$

Taking into consideration that in low power synchronous generators $z_r \gg r$, we simplify expressions (5) to the following:

$$R_{\text{нкр}} \approx z_r \sqrt{\frac{(k_{1i}'')^2 - (k_{1i}')^2}{(k_{1U}')^2 - (k_{1U}'')^2}}. \quad (6)$$

Thus, with load resistance over R_{Hkp} in all cases, the most advantageous is the bridge circuit of the rectifier. With large loads, it is necessary to select a one-half-period rectification circuit that in this area guarantees the greatest use of the generator.

Since the coefficients $\mathfrak{K}_{1U}$ and $\mathfrak{K}_{1i}$ are complex functions of the load, the number of phases, etc., then preliminary selection of the rectification circuit can be done based on an examination of the idealized rectifier. With this regard, the critical load resistance

$$R_{\text{нкр}} = z_r \cdot \frac{4}{\pi} \cdot \frac{\sin^2 \frac{\pi}{m}}{\frac{\pi}{m}}. \quad (7)$$

As is apparent from (7), the critical load resistance depends on the number of generator phases. Figure 3, illustrating this dependence, graphically shows that with an increase in the number of phases, the boundaries for the use of the bridge circuits are expanded, and with a fairly large number of phases, the circuits are practically identical. Therefore in designing direct current collector-free generators, as well as different types of collector-free exciters, the question of using a certain rectification circuit must be solved simultaneously with the question of selecting the number of phases, the parameters of the generator, as well as the

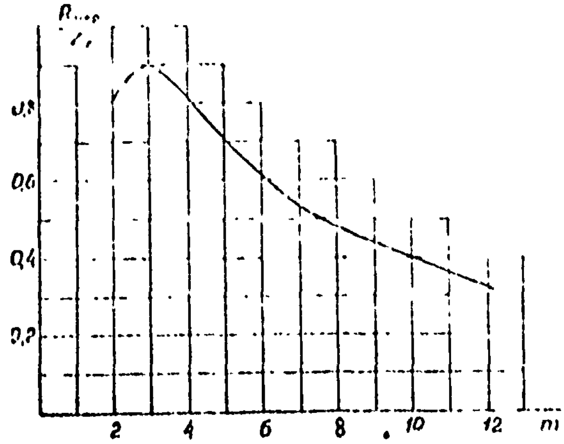

Figure 3. Dependence of $\frac{R_{Hkp}}{z_r}$ on Number of Phases.

necessary level of pulsations of the rectified voltage or current.

From this viewpoint, one can recommend for the exciters multiple-phase systems with one-half-period rectification circuit, and for generators that operate on high-ohmic load, bridge rectification circuits with relatively small number of phases.

References

1. А. П. Скороспешкин, Э. Ф. Оберган, Э. И. Подборский. Бесколлекторный электромашинный усилитель (БЭМУ). Известия ТПИ, том 145, 1966.

2. А. Ф. Крогерис. Режимы источников питания трехфазных мостовых выпрямительных схем. Диссертация, Рига, 1954

3. Г. А. Сипайлов, В. А. Зорин, Т. В. Кузнецова, А. Б. Цукублин. Некоторые вопросы работы маломощного синхронного генератора на выпрямительную нагрузку. Известия ТПИ, том 145, 1966.

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